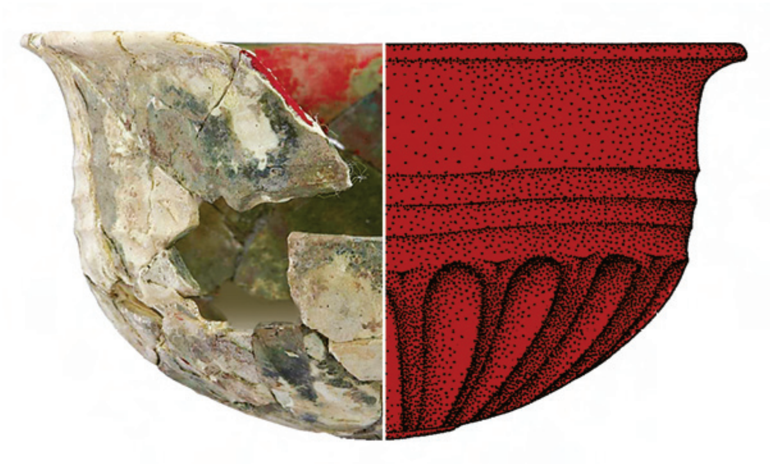
ANNALES



Thessaloniki 2009

du 18e CONGRÈS

de l'ASSOCIATION INTERNATIONALE
pour l'HISTOIRE du VERRE

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Editors
Despina Ignatiadou, Anastassios Antonaras

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Couverture / Cover illustration

The *haematinon* bowl from Pydna. Height 5.5 cm.

The bowl (skyphos) is discussed in the paper by Despina Ignatiadou 'A *haematinon* bowl from Pydna', p. 69.

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CONTENTS

HELLENISTIC GLASS

ROMAN GLASS

BYZANTINE AND EARLY ISLAMIC GLASS

BYZANTINE AND ISLAMIC GLASS

Medieval Glass

Post Byzantine / Venetian / Façon de Venise Glass

18th AND 19th CENTURY GLASS

AFRICAN AND ASIAN GLASS

PRÉFACE

Marie-Dominique Nenna

J'ai le grand plaisir de vous présenter les Annales du 18e congrès de l'Association Internationale pour l'Histoire du Verre et je tiens à remercier tous ceux qui ont fait que cette publication paraisse dans les meilleurs délais, les auteurs au premier chef, le comité de lecture et surtout les éditeurs du volume, Despina Ignatiadou, vice-présidente, puis membre du bureau de l'AIHV durant les années 2006-2012 et Anastassios Antonaras.

Le 18e congrès de l'AIHV s'est tenu à Thessalonique du 21 au 25 septembre 2009. Il a été dédié à Clasina Isings qui est venue, via une video, nous offrir ses meilleurs vœux au début des sessions. Tous nos remerciements vont d'abord au Musée archéologique de Thessalonique qui a organisé l'ensemble de cette manifestation et au Musée de la civilisation byzantine qui a accueilli nos sessions dans le tout nouveau auditorium, utilisé pour la première fois pour notre congrès. Remercions aussi les amis du Musée archéologique de Thessalonique qui ont soutenu ce congrès avec entre autres, le beau sac décoré de balsamaires-oiseaux ; la préfecture de Thessalonique qui nous ont accueillis à la fin de ces journées. Et enfin, du fond du coeur, tous nos remerciements vont à Despina Ignatiadou, Anastassios Antonaras et au comité d'organisation pour avoir réuni tous leurs efforts pour organiser ce congrès et nous offrir l'occasion de nous rencontrer une nouvelle fois pour partager nos découvertes et nos réflexions sur ce matériau qui nous passionne tous.

Durant les trente-trois sessions organisées en parallèle, 95 contributions orales et 55 posters ont été présentés, montrant ainsi la vitalité de la recherche sur l'Histoire du Verre dans l'ensemble du monde scientifique. Grâce au dynamisme du comité grec, après une découverte de la ville à l'orée de notre congrès, des promenades thématiques ont été organisées afin de mieux connaître les différents aspects de Thessalonique, ville hellénistique et romaine, ville byzantine, ville ottomane avec son importante communauté juive et ville du XXe siècle. En outre, les excursions post-congrès ont permis aux participants de découvrir le cœur de la Macédoine avec les cités de Vergina et de Dion, ainsi que le lac de Pikrolimni, producteur de natron dans l'Antiquité et encore aujourd'hui, les villes d'Amphipolis et de Philippes ou encore de faire une croisière autour du Mont Athos.

Ce volume réunit 84 contributions qui couvrent un arc chronologique très vaste depuis le deuxième millénaire av. J.-C. jusqu'à nos jours, et touchent à tous les aspects de l'histoire du verre, avec une bonne interconnexion entre l'archéologie, l'histoire de l'art et l'archéométrie. Une part importante est réservée aux débuts de l'histoire du verre au IIe millénaire et au début du Ier millénaire av. J.-C. et à ses développements dans le monde hellénistique avec des communications portant sur le Proche-Orient, l'Égypte et le Soudan, la Grèce et la Turquie. Les mondes romain et byzantin sont abordés selon deux axes : étude de la production et de la consommation de la vaisselle et des ornements et étude en fort développement de l'emploi du verre dans les mosaïques pavimentales et pariétales. Les communications sur le monde islamique s'inscrivent dans la lancée inaugurée au 15e congrès et attestent la vitalité de la recherche dans ce domaine. La présentation de découvertes et études portant sur la Grande Bretagne, l'Italie, le Kosovo, le Montenegro, le Portugal, la Pologne, la Roumanie, la Serbie et la Tchéquie alimentent le débat sur le verre à l'époque médiévale et post médiévale en Europe. XVIIIe et XIXe siècles ne sont pas en reste, avec des communications sur le verre dans les toits, les fleurs de verre et le verre mosaïqué et on dispose aussi de communications sur le verre en Chine méridionale et en Afrique subsaharienne.

Lors de l'assemblée générale, le bureau de l'AIHV a été renouvelé. Jan Egbert Kuipers, trésorier et Ian Freestone, que l'on doit remercier pour leur dévouement et leur efficacité, ont présenté leur démissions. De nouveaux membres ont été élus : Irena Lazar, organisatrice du 19e congrès en 2012, comme vice-présidente et Huib Tijssens, comme trésorier. Déjà présents dans le bureau, Despina Ignatiadou a été élue comme membre, Jane Spillman a été réélue comme secrétaire général, David Whitehouse comme membre, et j'ai moi-même été réélue comme présidente. Le comité exécutif réunissant six membres élus ainsi que les représentants des associations ou comités nationaux a été en partie renouvelé, avec l'élection de Fatma Marii et de Yoko Shindo, tandis que Sylvia Fünfschilling, Lisa Pilosi, Marianne Stern et Maria Grazia Diani ont été réélues. Nous avons déploré le décès lors du congrès de deux de nos membres, Sarah Jennings d'Angleterre et Claudia Maccabruni d'Italie.

Les préparatifs pour le 19e congrès se déroulent sous la houlette d'Irena Lazar. Le congrès se tiendra à Piran en Slovénie du 17 au 21 septembre 2012 (www.aihv.org, www.zrs.upr.si). Après l'accent mis sur la Méditerranée orientale au congrès de Thessalonique, une nouvelle avancée vers les informations et les membres d'Europe Centrale sera effectuée à Piran.

PREFACE

Marie-Dominique Nenna

I have great pleasure in presenting you with the Annales of the 18th congress of the Association Internationale pour l'Histoire du Verre, and I wish to thank all those who have ensured that this publication appears with the least delay: principally the authors, the academic committee, and especially the academic editors of the volume, Despina Ignatiadou, vice-president, and member of the board of the AIHV for the years 2006-2012 and Anastassios Antonaras.

The 18th congress of the AIHV was held in Thessaloniki from September 21st-25th, 2009. It was dedicated to Clasina Isings, who came, via a video, to offer us her best wishes. Here we have to warmly thank the Archaeological Museum of Thessaloniki which has organized the whole manifestation, and the Museum of Byzantine Culture, which has hosted our sessions in the brand new auditorium of the Museum, used for the first time for our congress. All our warm thanks also to The Friends of the Archaeological Museum of Thessaloniki who supported the organization of the congress among the others with the nice bag decorated with bird-balsamaria, and The Prefecture of Thessaloniki, who has hosted us at the end of the congress. Last, but not the least, from the bottom of our heart, our thanks go to Despina Ignatiadou, Anastassios Antonaras and the Organizing committee for their hard work in organizing this congress and for offering us the opportunity to meet once again to share our discoveries and our thoughts on this wonderful material, glass, to which we are all dedicated.

During the 33 parallel sessions, 95 oral communications and 55 posters were presented, displaying the vitality of research on the history of glass in the scientific world. Thanks to the energies of the Greek Committee, after a first glance at Thessaloniki at the beginning of our congress, thematic visits were organised to discover the different aspects of Thessaloniki· Hellenistic and Roman city, Byzantine city, Ottoman city with its important Jewish community, contemporary city. In the post-congress trips, the participants were able to visit the heart of Macedonia, with the cities of Vergina and Dion, and the Pikrolimni Lake, producing natron in Antiquity and still today, the ancient cities of Amphipolis and Philippi, or to make a cruise around Mount Athos.

This volume brings together 84 contributions, which cover a vast chronological span from the second millennium BC up to the present day, touching on all aspects of the history of glass with a good networking between archaeology, history of art and archaeometry. An important part is devoted to the beginnings of the history of glass in the second millennium and the beginning of the first millennium BC, and the developments in the Hellenistic world with papers covering the Near East, Egypt and Sudan, Greece and Turkey. The Roman and Byzantine worlds are approached from two directions: the study of the production and consumption of vessels and ornaments and the expanding study on the glass in mosaic pavements and walls. The papers on the Islamic world build on the start made at the 15th congress and show the vitality of research in this area. The presentation of discoveries and research coming from the Czech Republic, Great Britain, Italy, Kosovo, Montenegro, Portugal, Poland, Romania and Serbia, fuels the debates about glass during the medieval and post-medieval period in Europe. The 18th and 19th centuries are not ignored, with papers dealing with glass in roofs, glass flowers and mosaic glass and there are also studies dealing with African and Asian glass.

During the General Assembly the board of the AIHV changed. Jan Egbert Kuipers (Treasurer) and Ian Freestone, to whom we extend all thanks for their work, submitted their resignations. The newly elected members were Irena Lazar, organizer of the 19th Congress in 2012, as Vice President, and Huib Tijssens, as Treasurer. Already present in the board, Despina Ignatiadou was elected member, were re-elected Jane Spillman as General Secretary, David Whitehouse as member, and I as President. The executive committee which assembled six elected members as well as the presidents of the national Associations or Committees, was partly renewed, with the election of Fatma Marii and Yoko Shindo; Sylvia Fünfschilling, Lisa Pilosi, Marianne Stern et Maria Grazia Diani were re-elected. We mourned during the congress the recent death of two long time members, Sarah Jennings from England and Claudia Maccabruni from Italy.

The preparations for the 19th congress are progressing under the guidance of Irena Lazar. The congress will be held at Piran (Slovenia) from September 17th to September 21st 2012 (www.aihv.org, www.zrs.upr.si). After the wider opening towards eastern Mediterranean members effectuated during the Thessaloniki Congress, we will receive in Piran more information and members coming from Central Europe.

MEDITERRANEAN SAND DEPOSITS AS A RAW MATERIAL FOR GLASS PRODUCTION IN ANTIQUITY

Dieter Brems, Sara Boyen, Monica Ganio, Patrick Degryse, Marc Walton

1. Introduction

Natron glass was the predominant type of glass in the Mediterranean area and in Europe between the middle of the first millennium BC and the ninth century AD[1]. It was produced from its raw materials in so called 'primary' workshops based upon quartz sand with a soda-rich mineral flux (natron) and lime bearing material, shell or limestone. This raw glass was broken up and traded throughout the Mediterranean as chunks and then remelted, coloured if desired, and shaped into vessels and other objects in 'secondary' workshops. 'Primary' production centres, active from the 4th to 8th century, were identified in Egypt and Syro-Palestine[2]. The location of primary glass production in the Hellenistic and early Roman world is still up for intense debate and some authors have suggested that it also took place outside Egypt and the Levant[3]. Furthermore, the ancient author Pliny the Elder wrote in his Natural History (70 AD) that also sands from the coasts of Italy, Gaul and Spain were used to melt glass. This, however, was never confirmed by excavations or through scientific analysis.

In the past decade, several attempts have been made to determine the provenance of ancient glass based on major, minor and trace elemental compositions, rare earth element patterns and isotopic signatures of O, Pb, Sr and Nd[4]. In particular, trace elements and Nd isotopic signatures appear to be promising tracers for raw materials in glass production, since they may show systematic variations around the Mediterranean Sea as a consequence of the differing geological environment.

1. Freestone 2006.
2. Picon and Vichy 2003.
3. e.g. Jackson *et al.* 2003; Leslie *et al.* 2006.
4. e.g. Wedepohl and Baumann 2000; Freestone *et al.* 2003; Henderson *et al.* 2005; Shortland *et al.* 2007; Degryse and Schneider 2008; Degryse *et al.* 2009a.

2. The geology of the Mediterranean basin

The Mediterranean drainage basin consists of the integrated catchment areas of more than 160 rivers (with catchment >200 km^2) that drain to the Mediterranean Sea[5]. The whole basin covers an area of some 1,335,000 km^2, excluding the catchment area of the river Nile, which accounts for a further 2,800,000 km^2. The Mediterranean Sea can be divided geographically into three main areas[6]: (i) the western Mediterranean, which includes the Alboran Sea, the Balearic Sea and the Algerian Basin; (ii) the central Mediterranean, consisting of the Tyrrhenian Sea, the Adriatic Sea and the Ionian Sea; and (iii) the eastern Mediterranean, incorporating the Aegean Sea (and the adjacent Sea of Marmara) and the Levantine Sea. About 54% of the 46,133 km long present-day Mediterranean coastline is rocky with the remaining 46% consisting of various sedimentary accumulations[7]. These are in the form of sandy and pebbly beaches, dunes, deltas, estuaries, wetlands and lagoons. The largest modern deltas are those of the Nile in Egypt, the Rhone in France, the Po in Italy, the Ebro in Spain, the Ceyhan in Turkey, the Axios and Haliacmon in Greece and the Medjerda in Tunisia.

In a plate tectonic context, the Mediterranean basin forms the boundary zone between the Eurasian, the African and the Arabian plates. The structure of the basin is extremely complex, incorporating a number of smaller secondary or microplates which often have very different geological histories than the major plates[8]. This tectonic framework resulted in the formation of three rather distinct geological environments around the Mediterranean[9]. Firstly, the Precambrian African craton underlying North Afri-

5. Poulos and Collins 2002.
6. Carter *et al.* 1972; Poulos and Collins 2002.
7. Barić and Cašparović 1992.
8. Dewey *et al.* 1973.
9. Macklin *et al.* 1995.

ca mostly forms a low elevation desert environment. In the eastern Mediterranean it is diversified by rifting in Sinai and the Jordan Valley. Secondly, there are the folded and partly metamorphosed Variscan Massifs of the Iberian Peninsula, Corsica and Sardinia. In eastern Spain these are covered by flat-lying or gently folded Mesozoic and Cenozoic sediments. And thirdly, the Alpine fold belts (Atlas, Betics, Pyrenees, Alps, Dinarides, Hellenides, Taurides) form the northern morphological boundary of the Mediterranean drainage basin. Furthermore, the river Nile drains the north-eastern part of the African continent and derives the majority of its sediment load from the Ethiopian highlands which are dominated by Cenozoic volcanic rocks[10]. Because of these different geomorphological and tectonic settings, the Mediterranean can be divided into several catchment basins, where the sediments will reflect in their composition the main geological units, and their differences.

One of the characteristics that seem to vary throughout the Mediterranean sediments is the Nd isotopic composition. These differences in Nd isotopic signatures can occur due to the radiogenic growth of ^{143}Nd (because of decay of the radioactive ^{147}Sm isotope via alpha decay) in reservoirs with varying Sm/Nd ratios. These isotopic variations are expressed relative to the stable, non-radiogenic isotope ^{144}Nd (^{143}Nd/^{144}Nd ratio) and a sample's deviation from the value for the bulk earth at a given time is expressed using the epsilon notation ε_{Nd}:

$$\varepsilon_{Nd}(T) = \left[\frac{\left({}^{143}\mathrm{Nd} / {}^{144}\mathrm{Nd}_{\text{sample at time T}} \right)}{\left({}^{143}\mathrm{Nd} / {}^{144}\mathrm{Nd}_{\text{CHUR at time T}} \right)} - 1 \right] \times 10^4$$

where CHUR is a chondritic uniform reservoir, which represents a bulk earth Nd isotope composition[11]. Since different rock types can have different Nd isotopic compositions (e.g. young basaltic volcanic rocks show high ε_{Nd} values, typical continental crust with a range of crustal ages has intermediate values, and old continental crust has low Nd isotopic signatures) and because clastic sediments are in fact just mechanical disintegration products of igneous, metamorphic and older sedimentary rocks which are exposed in the source area, the Nd isotopic values of the sediments can help to identify the sediment source.

10. Foucault and Stanley 1989.
11. DePaolo and Wasserburg 1976.

Due to the varying sediment influx from the Nile (fluvial), the Sahara (aeolian) and the European continent (fluvial), the Nd isotopic composition of deep-sea sediments in the eastern Mediterranean Sea varies significantly. The river Nile has an exceptionally high Nd composition of its sediment load of around $-1\ \varepsilon_{Nd}$[12], as it is dominated by young volcanic rocks from the Ethiopian Plateau. Sediments dominated by input from wind-blown Saharan dusts, on the other hand, show typical low (old) Nd isotopic values of around $-13\ \varepsilon_{Nd}$[13]. Sediments entering the Ionian Sea from the Calabrian Arc and the Adriatic Sea are characterized by low Nd values of $-11\ \varepsilon_{Nd}$[14]. Aegean Sea sediments show average values of $-7\ \varepsilon_{Nd}$[15]. When these sediments enter the Mediterranean Sea, they are redistributed by the dominant sea currents[16]. For example, the Nile river sediments are transported eastwards along the Egyptian and Israelian coasts, possibly up to Turkey. Because of the combination of all these different sources and currents, the isotopic pattern of the eastern Mediterranean surface sediments shows a pronounced E-W gradient from as high as $-1\ \varepsilon_{Nd}$ at the mouth of the river Nile and the coasts of Egypt and Israel to $-12\ \varepsilon_{Nd}$ south of Sicily[17]. In the western Mediterranean, the distribution of the Nd isotopic signatures is less well known. Only a few results for particulates from the Rhône and the Po rivers and deep sea sediments near Gibraltar and the southern French coasts are published and they all show rather low signatures of around $-10\ \varepsilon_{Nd}$[18]. One result from the Tyrrhenian Sea values at $-7.6\ \varepsilon_{Nd}$[19]. Although the number of analysis is small, there seems to be a significant difference in Nd isotopic signatures between the easternmost part of the Mediterranean Sea and the rest of the basin.

3. Objectives

Nd in Hellenistic, Roman and Early Byzantine period glass (*i.e.*, natron based glass) originates from the heavy or non-quartz mineral fraction of the silica raw material[20]. Because of their relatively high masses and low internal mass differences, the isotopes of Nd would not be fractionated during technical processing

12. Weldeab *et al.* 2002; Scrivner *et al.* 2004.
13. Grousset *et al.* 1988, 1998.
14. Weldeab *et al.* 2002.
15. Weldeab *et al.* 2002.
16. Pinardi and Masetti 2000; Weldeab *et al.* 2002; Hamad *et al.* 2006.
17. Goldstein *et al.* 1984; Frost *et al.* 1986; Weldeab *et al.* 2002.
18. Frost *et al.* 1986; Grousset *et al.* 1988.
19. Frost *et al.* 1986.
20. Degryse and Schneider 2008.

Sample	Location	Latitude	Longitude	$^{143}Nd/^{144}Nd$	ε_{Nd}	Nd (ppm)
Spain						
SP08DB02	Benicassim	N40°2'45"	E0°3'56"	0.512018	-12.10	nd.
SP08FH03	Vilassar de Mar	N41°30'46"	E2°24'46"	0.512161	-9.30	10.85
SP08FH06	Riumar	N40°43'49"	E0°50'30"	0.512049	-11.49	9.19
SP08FH11	Platja d'Aro	N41°49'02"	E3°04'11"	0.512193	-8.68	3.59
Italy						
IT08DB01	Cala Violina	N42°54'59"	E10°45'45"	0.512184	-8.86	nd.
IT08DB02	Amalfi	N40°37'7"	E14°34'38"	0.512415	-4.35	nd.
IT08DB03	Ravenna, Uniti estuary	N44°23'39"	E12°18'56"	0.511969	-13.05	nd.
IT08DB04	San Benedetto del Tronto	N42°57'57"	E13°52'48"	0.512173	-9.07	nd.
IT08DB05	Elba	N42°47'34"	E10°14'57"	0.512428	-4.10	nd.
IT08DB06	Ostia	N41°43'41"	E12°16'40"	0.512138	-9.76	nd.
IT08DB07	Gargano	N41°56'11"	E15°56'50"	0.512245	-7.67	nd.
IT08DB08	Torre Salsa, Sicily	N37°22'51"	E13°18'22"	0.512067	-11.14	nd.
IT09DB09	Viareggio	N43°49'28"	E10°15'15"	0.512236	-7.84	nd.
IT09DB10	Cervia	N44°15'51"	E12°21'34"	0.512211	-8.34	nd.
IT09DB11	Castellaneta Marina	N40°27'45"	E16°56'18"	0.512194	-8.66	nd.
IT09DB20	Licola Mare	N40°52'5"	E14° 2'37"	0.512284	-6.90	59.5
IT09DB21	Castel Volturno, river Volturno mouth	N41°1'15"	E13°55'50"	0.512411	-4.40	296.3
IT09DB22	Gaeta	N41°12'47"	E13°32'33"	0.512133	-9.90	25.2
Greece						
GR08DB01	Acharavi, Korfu	N39°47'54"	E19°49'1"	0.512304	-6.51	nd.
Turkey						
TU08DB01	Gümbet	N37°01'52"	E27°24'17"	0.512259	-7.40	nd.
Israel						
IS08DB01	Akko, river Belus mouth	N32°54'32"	E35°04'53"	0.512393	-4.80	19.7
IS08DB02	Akko, river Belus mouth	N32°54'32"	E35°04'53"	0.512392	-4.80	25.9
IS08DB03	Akko, 400 m south of the river Belus mouth	N32°54'17"	E35°04'52"	0.512588	-1.00	23.7

Table 1: Nd isotopic data of beach sands (nd.: not determined).

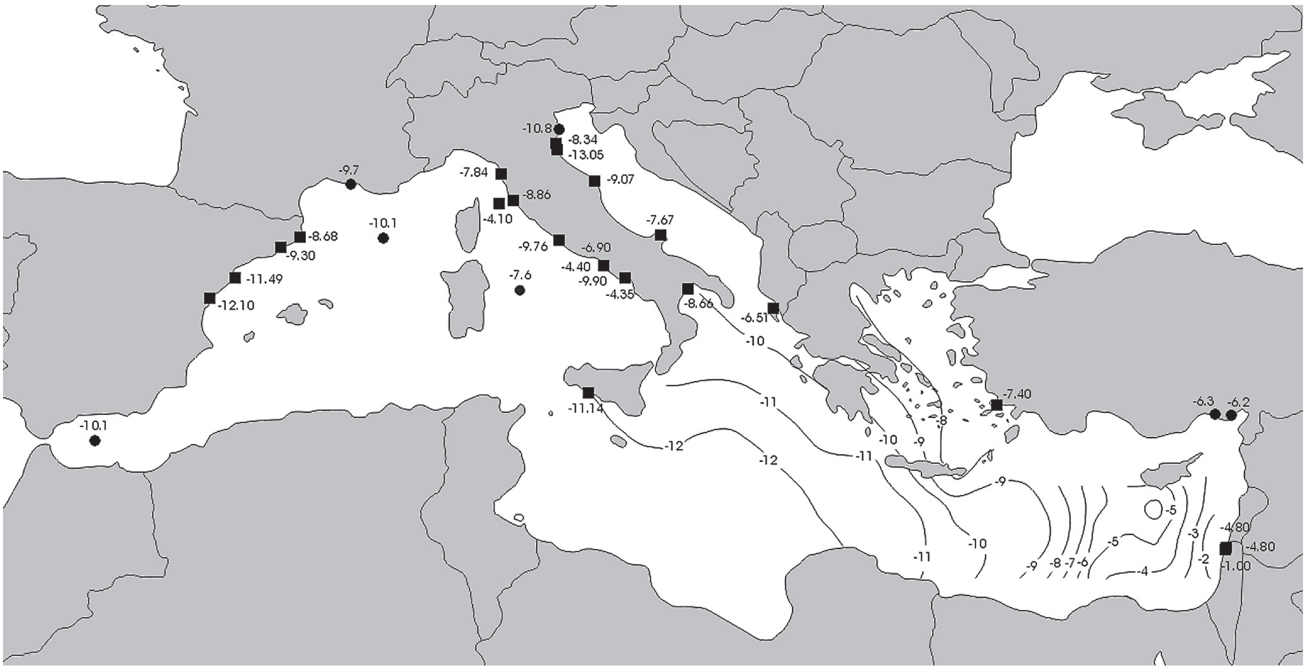

Fig. 1: Map with the sampling localities and the ε_{Nd} values of the sands reported in this study (squares). The circles correspond to ε_{Nd} signatures published in literature (see text) and the contour lines in the eastern Mediterranean represent the Nd isotopic composition of lithogenic surface sediments as reported by Weldeab *et al.* (2002).

like glass melting[21] and therefore the isotopic composition of the glass artefact would be identical to that of the raw materials from which it was derived. So the difference in Nd isotopic compositions between sediments in the eastern and western part of the Mediterranean basin offers a great potential to distinguish primary glass from Egypt and the Levant from other primary glass producers. However, it is of course not possible to directly compare the Nd signature of glass to that of sea-floor sediments. Sand deposits are often much more locally derived and it isn't certain that these beach sands show the same regional variations in Nd isotopic composition.

This paper therefore investigates whether variations in Nd isotopic signatures can distinguish sand deposits around the Mediterranean. 23 beach sand samples from Spain, Italy, Greece, Turkey and Israel are analysed for their Nd isotopic compositions and it is looked into whether the regional pattern in Nd isotopic signatures of deep-sea sediments can be recognized in these beach sands, which may have been used in Roman glass production. The range of sand isotopic signatures is then compared to that of Roman-Byzantine natron glass from around the Mediterranean. In this way, the occurrence of primary production centres of raw glass outside the Levant and Egypt, and in particular in Italy, Gaul and Spain, can be investigated.

4. Results and discussion

4.1. Beach sand

In general, the measured Nd isotopic signatures of the beach sands are consistent with the data from the deep sea sediments[22] showing a decrease in ε_{Nd} from east to west (Table 1; Fig. 1 and 2). The Spanish sands show Nd isotopic values from −12 to −8 ε_{Nd}. The Italian samples mostly cluster between −10 and −7 ε_{Nd}, and Greek and Turkish sands have Nd values between −7.5 and −6.5 ε_{Nd}. However, we have to note that local variations do occur due to volcanic activity. Three of the Italian sand samples (IT08DB02, IT08DB05 and IT09DB21), which are derived from Pleistocene rhyolitic volcanic rocks, show isotopic compositions of around −4.3 ε_{Nd}. These sands are very dark and contain high percentages of heavy minerals, from 30 up to almost 90 %, and are not suitable as raw materials for glass production because of their very high Fe and Al levels and low Si content. Beach sands from the eastern Mediterranean coasts near the mouth of the river Belus, which were sampled by R.H. Brill in the sixties[23], show high Nd isotopic signature, i.e. higher than −5 ε_{Nd}. Sample IS08DB03 is a mixture of samples taken 400 m south of the river mouth. This sand has a Nd isotopic value of −1.0 ε_{Nd}, indicating the dominance of material coming from the Nile. Samples IS08DB01 and IS08DB02 are fine sands from the beach at the mouth of the river Belus and have Nd signatures of −4.8 ε_{Nd}. This somewhat lower value can be explained by mixing sands derived from the Nile with more local material, delivered by the Belus itself, with a more radiogenic (lower) Nd isotopic signature.

Furthermore it must be stressed that this regional systematic variation is only to be expected for beach sands. Local inland (e.g. quarry) sands from the eastern Mediterranean will not be influenced by the high ε_{Nd} value of Nile sediments and will retain their own (probably low) Nd signature, indistinguishable from beach sands in the west. In this case, Sr isotopic signatures may be used to distinguish beach sand from inland sand[24].

4.2. Glass

Roman-Byzantine natron glass from around the Mediterranean shows a wide range of Nd isotopic signatures (Table 2; Fig. 3)[25]. The Nd signatures of the 1st-5th century natron glass vary considerably between −2.5 and −13.0 ε_{Nd}. 6th-7th century glass shows a much smaller range, between −4.3 and −5.7 ε_{Nd}.

A comparison between the ranges of the isotopic characteristics of sands and archaeological natron glasses from around the Mediterranean and Europe, suggests primary production in both the east and west. Nd isotopic signatures higher than −6 point to an eastern Mediterranean origin, while signatures lower than −6 correspond to the isotopic values of sediments in the western Mediterranean (cfr. Fig. 2). The large spread in the isotopic composition of the Roman glass, may suggest primary production of glass all over the Mediterranean, but can also result from intense recycling of glass with different primary origins and thus different signatures. Imagine, for example, that at a certain point in time there were three primary production centres at different places around the Medi-

21. Faure 1986.
22. Goldstein *et al.* 1984; Frost *et al.* 1986; Grousset *et al.* 1988; Weldeab *et al.* 2002.
23. Brill 1999.
24. e.g. Freestone *et al.* 2003
25. Degryse and Schneider 2008; Degryse *et al.* 2008; Degryse *et al.* 2009b.

Table 2:
Nd isotopic data
of archaeological glass
(nd.: not determined).
(1) Degryse and Schneider (2008);
(2) Degryse *et al.* (2008);
(3) Degryse *et al.* (2009b);
(4) Unpublished data.

Sample	Age	$^{143}Nd/^{144}Nd$	ε_{Nd}	Nd (ppm)	Reference
Maastricht					
Ma 1c	1st-3rd century	0.512214	-8.3	nd.	(1)
Ma 2 b	1st-3rd century	0.512205	-8.4	nd.	(1)
Ma 3 a	first half 3rd century	0.512343	-5.7	nd.	(1), (3)
Ma 5 b	second quarter 5th century	0.51218	-8.9	nd.	(3)
Tienen					
Tie 11	2nd century	0.512511	-2.5	15.4	(1), (3)
Tie 12	2nd century	0.512267	-7.2	13.9	(1), (3)
Tie 17	2nd century	0.512378	-5.1	18.7	(1), (3)
Tie 24	2nd century	0.512376	-5.1	18.7	(1), (3)
Tie 35	2nd century	0.512219	-8.2	nd.	(1), (3)
Tie 37	2nd century	0.512083	-10.8	nd.	(1), (3)
Tie 41	2nd century	0.512337	-5.9	28.9	(1), (3)
Tie 45	2nd century	0.512174	-9.1	nd.	(1), (3)
Tie 48	2nd century	0.512262	-7.3	nd.	(1), (3)
Tie 49	2nd century	0.512249	-7.6	nd.	(1), (3)
Tie 50	2nd century	0.512362	-5.4	18.2	(1), (3)
Bocholtz					
Bo 106	last quarter 2nd century	0.512296	-6.7	4.1	(1), (3)
Bo 109	late 2nd-early 3rd century	0.512298	-6.6	3.2	(1), (3)
Bo 119	1st-3rd century	0.512223	-8.1	5.9	(1)
Bo 123	late 2nd-early 3rd century	0.512291	-6.8	4.4	(1), (3)
Kelemantia					
Kel 82/91	AD 175-179	0.512325	-6.1	14.4	(1), (3)
Kel 229/06	AD 175-179	0.512266	-7.3	13.1	(1), (3)
Kel 229/88	AD 175-179	0.512325	-6.1	22.6	(1), (3)
Kel 234/88	AD 175-179	0.512177	-9.0	11.8	(1), (3)
Kel 300/06	3rd century	0.512336	-5.9	nd.	(3)
Sagalassos					
Sag 573	1st-3rd century	0.512294	-6.7	nd.	(1), (2)
Sag 574	1st-3rd century	0.512464	-3.4	nd.	(1), (2)
Sag 709	1st-3rd century	0.512308	-6.4	nd.	(1), (2)
Sag 575	1st-3rd century	0.512434	-4.0	nd.	(1), (2)
Sag 717	1st-3rd century	0.512410	-4.4	nd.	(1), (2)
Sag 718	1st-3rd century	0.512291	-6.8	nd.	(1), (2)
Sag 721	1st-3rd century	0.512392	-4.8	nd.	(2), (3)
Sag 723	1st-3rd century	0.512428	-4.1	nd.	(2), (3)
Sag 724	1st-3rd century	0.512377	-5.1	nd.	(2), (3)
Sag 579	4th-5th century	0.512351	-5.6	nd.	(2), (3)
Sag 580	4th-5th century	0.511972	-13.0	nd.	(2), (3)
Sag 713	4th-5th century	0.512387	-4.9	nd.	(2), (3)
Sag H54	6th-7th century	0.512407	-4.5	nd.	(2), (3)
Sag 714	6th-7th century	0.512407	-4.5	nd.	(2), (3)
Sag 583	6th-7th century	0.512382	-5.0	nd.	(2), (3)
Sag 589	6th-7th century	0.512382	-5.0	nd.	(2), (3)
SA04VL8A	6th-7th century	0.512346	-5.7	nd.	(2), (3)
SA00JP16	6th-7th century	0.512382	-5.0	nd.	(2), (3)
SA00JP28	6th-7th century	0.512382	-5.0	nd.	(2), (3)
Sag 588	6th-7th century	0.512418	-4.3	nd.	(2), (3)
SA04VL8B	6th-7th century	0.512387	-4.9	nd.	(2), (3)
Sag 586	6th-7th century	0.512371	-5.2	nd.	(2), (3)
SA00JP25B	6th-7th century	0.512351	-5.6	nd.	(2), (3)
SA04VL4	6th-7th century	0.512351	-5.6	nd.	(2), (3)

Sample	Age	$^{143}Nd/^{144}Nd$	ε_{Nd}	Nd (ppm)	Reference
Sant Boi de Llobregat, Sant Honorat					
PD 2	1st-2nd century	0.512375	-5.1	nd.	(4)
PD 4	1st-2nd century	0.512330	-6.0	6.2	(4)
PD 6	1st-2nd century	0.512217	-8.2	nd.	(4)
PD 9	1st-2nd century	0.512371	-5.2	nd.	(4)
PD 10	1st-2nd century	0.512414	-4.4	5.48	(4)
PD 11	1st-2nd cent AD	0.512360	-5.4	nd.	(4)
PD 14	1st-2nd cent AD	0.512410	-4.4	nd.	(4)
PD 15	1st-2nd cent AD	0.512439	-3.9	5.2	(4)

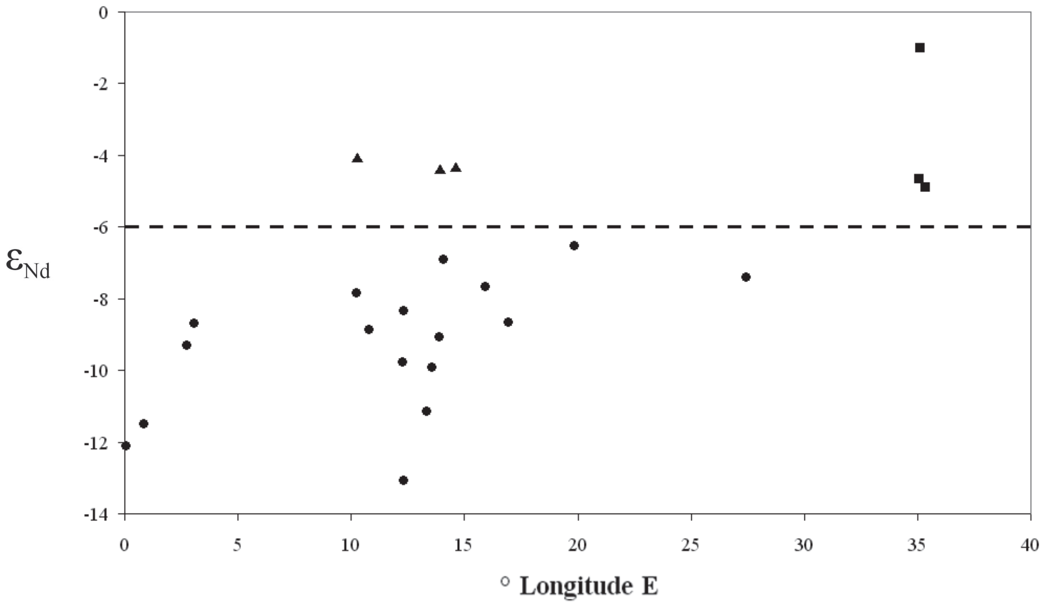

Fig. 2: Longitude versus ε_{Nd} biplot of the analysed beach sands showing the distinction between the eastern (squares) and western (circles) Mediterranean. The triangles represent the Italian volcanic sands with high ε_{Nd} values (see text). The dashed line corresponds to the –6 ε_{Nd}.

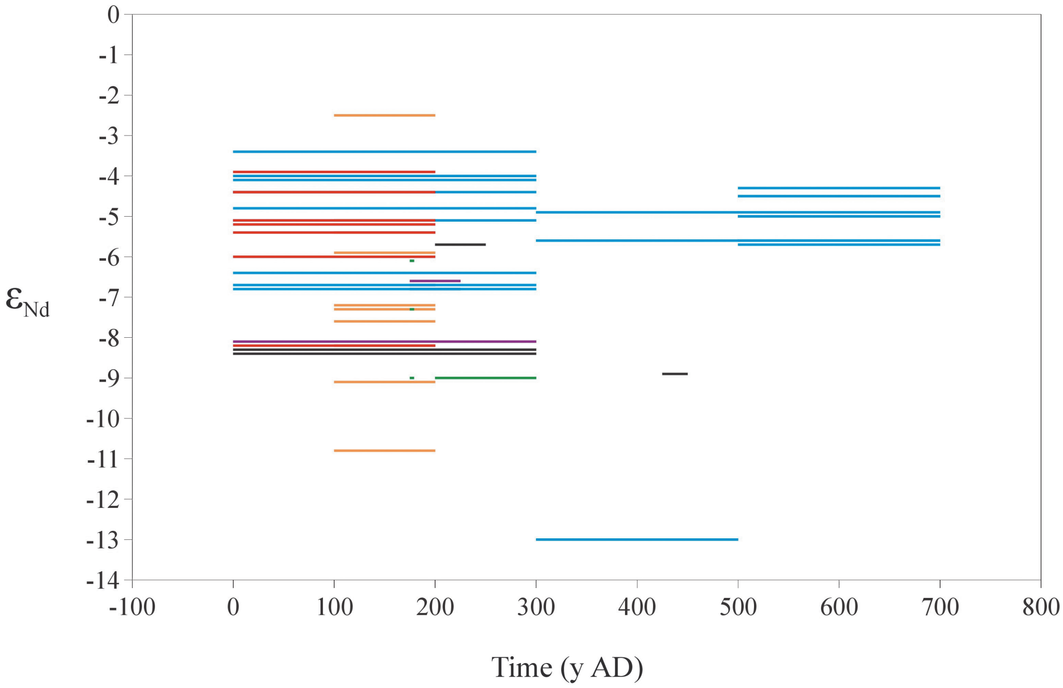

Fig. 3: Time versus ε_{Nd} biplot of Roman-Byzantine glasses from Maastricht (black), Tienen (orange), Bocholtz (purple), Kelemantia (green), Sagalassos (blue), and Sant Boi de Llobregat and Sant Honorat (red). References: see table 2.

terranean Sea. Each of these would have used its own local sand raw material with its own typical Nd isotopic signature, e.g. one around −3 ε_{Nd}, one around −5 ε_{Nd} and one around −11 ε_{Nd}. If the glass from these three producers was not mixed or recycled together with the glass from other sources, three distinct glass groups would appear, each one showing its own Nd isotopic signature. If however recycling was a common process, as it most probably was[26], the isotopic signatures would be smeared out between the highest and lowest values. In this case the intermediate signature of the second workshop is obscured. When later two of the workshops would stop producing glass, due to any possible reason, their signatures would not disappear abruptly but they would still remain visible for quite some time due to the recycling effects, resulting in a gradually narrowing of the isotopic range. This effect may be visible in figure 3. However, since this hypothesis is based on only 12 glass samples from a single site, it is too early to jump to conclusions. The length of the period in which the signature of the former glass producers remains visible in the glass record is very difficult to estimate and would depend on the intensity of recycling, the ratio between recycling of old glass and new raw production, the concentration of Nd in the different glass types, etc.

In this aspect we must stress the importance of working with multiple approaches, because only a combination of typological, chemical and isotopic analysis of well dated samples can result in pinpointing important events in the history of glass production and trade.

5. Conclusions

Nd isotopic signatures of beach sand deposits from around the Mediterranean Sea appear to show the same regional variations as deep-sea sediments offering a great potential to distinguish different sand raw materials and ultimately raw glass across the Mediterranean. More work is needed to construct an extensive database with sand isotopic signatures as a comparison for ancient glass. Local anomalies in ε_{Nd} of sands do occur due to recent volcanic activity. These sands however contain high Fe and Al levels and could not be used for glass production. This shows the necessity to evaluate the suitability for glass production and the Nd isotopic signature of the sand on a case to case basis.

Roman-Byzantine natron glasses show a wide range of Nd isotopic compositions. This may suggest raw glass production all around the Mediterranean Sea but can also reflect intense recycling of glass from a few big glass producers scattered around the Mediterranean.

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